Learning Objectives for AP® Physics

These course objectives are intended to elaborate on the content outline for Physics B and Physics C found in the *AP® Physics Course Description*. In addition to the five major content areas of physics, objectives are included now for laboratory skills, which have become an important part of the AP Physics Exams.

The objectives listed below are generally representative of the cumulative content of recently administered exams, although no single exam can cover them all. The checkmarks indicate the objectives that may be covered in either the Physics B or Physics C Exams.

It is reasonable to expect that future exams will continue to sample primarily from among these objectives. However, there may be an occasional question that is within the scope of the included topics but is not specifically covered by one of the listed objectives. Questions may also be based on variations or combinations of these objectives, rephrasing them but still assessing the essential concepts.

The objectives listed below are continually revised to keep them as current as possible with the content outline in the *AP Physics Course Description* and the coverage of the exams. However, the Course Description is always the most up-to-date, authoritative source for AP Physics course content.

The Development Committee for the AP Physics Exams welcomes comments and/or suggestions for additions or deletions to the course content from both high school and college physics teachers.

Objectives for the AP® Physics Courses	**AP Course**	
	B	**C**
I. NEWTONIAN MECHANICS		
A. Kinematics (including vectors, vector algebra, components of vectors, coordinate systems, displacement, velocity, and acceleration)		
1. Motion in one dimension		
a) Students should understand the general relationships among position, velocity, and acceleration for the motion of a particle along a straight line, so that:		
(1) Given a graph of one of the kinematic quantities, position, velocity, or acceleration, as a function of time, they can recognize in what time intervals the other two are positive, negative, or zero, and can identify or sketch a graph of each as a function of time.	✓	✓
(2) Given an expression for one of the kinematic quantities, position, velocity, or acceleration, as a function of time, they can determine the other two as a function of time, and find when these quantities are zero or achieve their maximum and minimum values.		✓
b) Students should understand the special case of motion with constant acceleration, so they can:		
(1) Write down expressions for velocity and position as functions of time, and identify or sketch graphs of these quantities.	✓	✓
(2) Use the equations $\upsilon = \upsilon_0 + at$, $x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$, and $\upsilon^2 = \upsilon_0^2 + 2a(x - x_0)$ to solve problems involving one-dimensional motion with constant acceleration.	✓	✓
c) Students should know how to deal with situations in which acceleration is a specified function of velocity and time so they can write an appropriate differential equation and solve it for $\upsilon(t)$ by separation of variables, incorporating correctly a given initial value of υ.		✓

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2. Motion in two dimensions, including projectile motion		
a) Students should be able to add, subtract, and resolve displacement and velocity vectors, so they can:		
(1) Determine components of a vector along two specified, mutually perpendicular axes.	✓	✓
(2) Determine the net displacement of a particle or the location of a particle relative to another.	✓	✓
(3) Determine the change in velocity of a particle or the velocity of one particle relative to another.	✓	✓
b) Students should understand the general motion of a particle in two dimensions so that, given functions $x(t)$ and $y(t)$ which describe this motion, they can determine the components, magnitude, and direction of the particle's velocity and acceleration as functions of time.		✓
c) Students should understand the motion of projectiles in a uniform gravitational field, so they can:		
(1) Write down expressions for the horizontal and vertical components of velocity and position as functions of time, and sketch or identify graphs of these components.	✓	✓
(2) Use these expressions in analyzing the motion of a projectile that is projected with an arbitrary initial velocity.	✓	✓
B. Newton's laws of motion		
1. Static equilibrium (first law) Students should be able to analyze situations in which a particle remains at rest, or moves with constant velocity, under the influence of several forces.	✓	✓
2. Dynamics of a single particle (second law)		
a) Students should understand the relation between the force that acts on an object and the resulting change in the object's velocity, so they can:		
(1) Calculate, for an object moving in one dimension, the velocity change that results when a constant force F acts over a specified time interval.	✓	✓
(2) Calculate, for an object moving in one dimension, the velocity change that results when a force $F(t)$ acts over a specified time interval.		✓
(3) Determine, for an object moving in a plane whose velocity vector undergoes a specified change over a specified time interval, the average force that acted on the object.	✓	✓
b) Students should understand how Newton's Second Law, $\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$, applies to an object subject to forces such as gravity, the pull of strings, or contact forces, so they can:		
(1) Draw a well-labeled, free-body diagram showing all real forces that act on the object.	✓	✓
(2) Write down the vector equation that results from applying Newton's Second Law to the object, and take components of this equation along appropriate axes.	✓	✓
c) Students should be able to analyze situations in which an object moves with specified acceleration under the influence of one or more forces so they can determine the magnitude and direction of the net force, or of one of the forces that makes up the net force, such as motion up or down with constant acceleration.	✓	✓

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d) Students should understand the significance of the coefficient of friction, so they can:		
(1) Write down the relationship between the normal and frictional forces on a surface.	✓	✓
(2) Analyze situations in which an object moves along a rough inclined plane or horizontal surface.	✓	✓
(3) Analyze under what circumstances an object will start to slip, or to calculate the magnitude of the force of static friction.	✓	✓
e) Students should understand the effect of drag forces on the motion of an object, so they can:		
(1) Find the terminal velocity of an object moving vertically under the influence of a retarding force dependent on velocity.	✓	✓
(2) Describe qualitatively, with the aid of graphs, the acceleration, velocity, and displacement of such a particle when it is released from rest or is projected vertically with specified initial velocity.		✓
(3) Use Newton's Second Law to write a differential equation for the velocity of the object as a function of time.		✓
(4) Use the method of separation of variables to derive the equation for the velocity as a function of time from the differential equation that follows from Newton's Second Law.		✓
(5) Derive an expression for the acceleration as a function of time for an object falling under the influence of drag forces.		✓
3. Systems of two or more objects (third law)		
a) Students should understand Newton’s Third Law so that, for a given system, they can identify the force pairs and the objects on which they act, and state the magnitude and direction of each force.	✓	✓
b) Students should be able to apply Newton’s Third Law in analyzing the force of contact between two objects that accelerate together along a horizontal or vertical line, or between two surfaces that slide across one another.	✓	✓
c) Students should know that the tension is constant in a light string that passes over a massless pulley and should be able to use this fact in analyzing the motion of a system of two objects joined by a string.	✓	✓
d) Students should be able to solve problems in which application of Newton’s laws leads to two or three simultaneous linear equations involving unknown forces or accelerations.	✓	✓
C. Work, energy, power		
1. Work and the work-energy theorem		
a) Students should understand the definition of work, including when it is positive, negative, or zero, so they can:		
(1) Calculate the work done by a specified constant force on an object that undergoes a specified displacement.	✓	✓
(2) Relate the work done by a force to the area under a graph of force as a function of position, and calculate this work in the case where the force is a linear function of position.	✓	✓
(3) Use integration to calculate the work performed by a force $F(x)$ on an object that undergoes a specified displacement in one dimension.		✓
(4) Use the scalar product operation to calculate the work performed by a specified constant force F on an object that undergoes a displacement in a plane.	✓	✓

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b) Students should understand and be able to apply the work-energy theorem, so they can:		
(1) Calculate the change in kinetic energy or speed that results from performing a specified amount of work on an object.	✓	✓
(2) Calculate the work performed by the net force, or by each of the forces that make up the net force, on an object that undergoes a specified change in speed or kinetic energy.	✓	✓
(3) Apply the theorem to determine the change in an object's kinetic energy and speed that results from the application of specified forces, or to determine the force that is required in order to bring an object to rest in a specified distance.	✓	✓
2. Forces and potential energy		
a) Students should understand the concept of a conservative force, so they can:		
(1) State alternative definitions of "conservative force" and explain why these definitions are equivalent.		✓
(2) Describe examples of conservative forces and non-conservative forces.		✓
b) Students should understand the concept of potential energy, so they can:		
(1) State the general relation between force and potential energy, and explain why potential energy can be associated only with conservative forces.		✓
(2) Calculate a potential energy function associated with a specified one-dimensional force $F(x)$.		✓
(3) Calculate the magnitude and direction of a one-dimensional force when given the potential energy function $U(x)$ for the force.		✓
(4) Write an expression for the force exerted by an ideal spring and for the potential energy of a stretched or compressed spring.	✓	✓
(5) Calculate the potential energy of one or more objects in a uniform gravitational field.	✓	✓
3. Conservation of energy		
a) Students should understand the concepts of mechanical energy and of total energy, so they can:		
(1) State and apply the relation between the work performed on an object by non-conservative forces and the change in an object's mechanical energy.		✓
(2) Describe and identify situations in which mechanical energy is converted to other forms of energy.	✓	✓
(3) Analyze situations in which an object's mechanical energy is changed by friction or by a specified externally applied force.	✓	✓
b) Students should understand conservation of energy, so they can:		
(1) Identify situations in which mechanical energy is or is not conserved.	✓	✓
(2) Apply conservation of energy in analyzing the motion of systems of connected objects, such as an Atwood's machine.	✓	✓
(3) Apply conservation of energy in analyzing the motion of objects that move under the influence of springs.	✓	✓
(4) Apply conservation of energy in analyzing the motion of objects that move under the influence of other non-constant one-dimensional forces.		✓
c) Students should be able to recognize and solve problems that call for application both of conservation of energy and Newton's Laws.		✓

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4. Power Students should understand the definition of power, so they can:		
a) Calculate the power required to maintain the motion of an object with constant acceleration (e.g., to move an object along a level surface, to raise an object at a constant rate, or to overcome friction for an object that is moving at a constant speed).	✓	✓
b) Calculate the work performed by a force that supplies constant power, or the average power supplied by a force that performs a specified amount of work.	✓	✓
D. Systems of particles, linear momentum		
1. Center of mass		
a) Students should understand the technique for finding center of mass, so they can:		
(1) Identify by inspection the center of mass of a symmetrical object.		✓
(2) Locate the center of mass of a system consisting of two such objects.		✓
(3) Use integration to find the center of mass of a thin rod of non-uniform density		✓
b) Students should be able to understand and apply the relation between center-of-mass velocity and linear momentum, and between center-of-mass acceleration and net external force for a system of particles.		✓
c) Students should be able to define center of gravity and to use this concept to express the gravitational potential energy of a rigid object in terms of the position of its center of mass.		✓
2. Impulse and momentum Students should understand impulse and linear momentum, so they can:		
a) Relate mass, velocity, and linear momentum for a moving object, and calculate the total linear momentum of a system of objects.	✓	✓
b) Relate impulse to the change in linear momentum and the average force acting on an object.	✓	✓
c) State and apply the relations between linear momentum and center-of-mass motion for a system of particles.		✓
d) Calculate the area under a force versus time graph and relate it to the change in momentum of an object.	✓	✓
e) Calculate the change in momentum of an object given a function $F(t)$ for the net force acting on the object.		✓
3. Conservation of linear momentum, collisions		
a) Students should understand linear momentum conservation, so they can:		
(1) Explain how linear momentum conservation follows as a consequence of Newton's Third Law for an isolated system.		✓
(2) Identify situations in which linear momentum, or a component of the linear momentum vector, is conserved.	✓	✓
(3) Apply linear momentum conservation to one-dimensional elastic and inelastic collisions and two-dimensional completely inelastic collisions.	✓	✓
(4) Apply linear momentum conservation to two-dimensional elastic and inelastic collisions.		✓
(5) Analyze situations in which two or more objects are pushed apart by a spring or other agency, and calculate how much energy is released in such a process.	✓	✓

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b) Students should understand frames of reference, so they can:		
(1) Analyze the uniform motion of an object relative to a moving medium such as a flowing stream.		✓
(2) Analyze the motion of particles relative to a frame of reference that is accelerating horizontally or vertically at a uniform rate.		✓
E. Circular motion and rotation		
1. Uniform circular motion Students should understand the uniform circular motion of a particle, so they can:		
a) Relate the radius of the circle and the speed or rate of revolution of the particle to the magnitude of the centripetal acceleration.	✓	✓
b) Describe the direction of the particle's velocity and acceleration at any instant during the motion.	✓	✓
c) Determine the components of the velocity and acceleration vectors at any instant, and sketch or identify graphs of these quantities.	✓	✓
d) Analyze situations in which an object moves with specified acceleration under the influence of one or more forces so they can determine the magnitude and direction of the net force, or of one of the forces that makes up the net force, in situations such as the following:		
(1) Motion in a horizontal circle (e.g., mass on a rotating merry-go-round, or car rounding a banked curve).	✓	✓
(2) Motion in a vertical circle (e.g., mass swinging on the end of a string, cart rolling down a curved track, rider on a Ferris wheel).	✓	✓
2. Torque and rotational statics		
a) Students should understand the concept of torque, so they can:		
(1) Calculate the magnitude and direction of the torque associated with a given force.	✓	✓
(2) Calculate the torque on a rigid object due to gravity.	✓	✓
b) Students should be able to analyze problems in statics, so they can:		
(1) State the conditions for translational and rotational equilibrium of a rigid object.	✓	✓
(2) Apply these conditions in analyzing the equilibrium of a rigid object under the combined influence of a number of coplanar forces applied at different locations.	✓	✓
c) Students should develop a qualitative understanding of rotational inertia, so they can:		
(1) Determine by inspection which of a set of symmetrical objects of equal mass has the greatest rotational inertia.		✓
(2) Determine by what factor an object's rotational inertia changes if all its dimensions are increased by the same factor.		✓
d) Students should develop skill in computing rotational inertia so they can find the rotational inertia of:		
(1) A collection of point masses lying in a plane about an axis perpendicular to the plane.		✓
(2) A thin rod of uniform density, about an arbitrary axis perpendicular to the rod.		✓
(3) A thin cylindrical shell about its axis, or an object that may be viewed as being made up of coaxial shells.		✓
e) Students should be able to state and apply the parallel-axis theorem.		✓

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3. Rotational kinematics and dynamics		
a) Students should understand the analogy between translational and rotational kinematics so they can write and apply relations among the angular acceleration, angular velocity, and angular displacement of an object that rotates about a fixed axis with constant angular acceleration.		✓
b) Students should be able to use the right-hand rule to associate an angular velocity vector with a rotating object.		✓
c) Students should understand the dynamics of fixed-axis rotation, so they can:		
(1) Describe in detail the analogy between fixed-axis rotation and straight-line translation.		✓
(2) Determine the angular acceleration with which a rigid object is accelerated about a fixed axis when subjected to a specified external torque or force.		✓
(3) Determine the radial and tangential acceleration of a point on a rigid object.		✓
(4) Apply conservation of energy to problems of fixed-axis rotation.		✓
(5) Analyze problems involving strings and massive pulleys.		✓
d) Students should understand the motion of a rigid object along a surface, so they can:		
(1) Write down, justify, and apply the relation between linear and angular velocity, or between linear and angular acceleration, for an object of circular cross-section that rolls without slipping along a fixed plane, and determine the velocity and acceleration of an arbitrary point on such an object.		✓
(2) Apply the equations of translational and rotational motion simultaneously in analyzing rolling with slipping.		✓
(3) Calculate the total kinetic energy of an object that is undergoing both translational and rotational motion, and apply energy conservation in analyzing such motion.		✓
4. Angular momentum and its conservation		
a) Students should be able to use the vector product and the right-hand rule, so they can:		
(1) Calculate the torque of a specified force about an arbitrary origin.		✓
(2) Calculate the angular momentum vector for a moving particle.		✓
(3) Calculate the angular momentum vector for a rotating rigid object in simple cases where this vector lies parallel to the angular velocity vector.		✓
b) Students should understand angular momentum conservation, so they can:		
(1) Recognize the conditions under which the law of conservation is applicable and relate this law to one- and two-particle systems such as satellite orbits.		✓
(2) State the relation between net external torque and angular momentum, and identify situations in which angular momentum is conserved.		✓
(3) Analyze problems in which the moment of inertia of an object is changed as it rotates freely about a fixed axis.		✓
(4) Analyze a collision between a moving particle and a rigid object that can rotate about a fixed axis or about its center of mass.		✓
F. Oscillations and Gravitation		
1. Simple harmonic motion (dynamics and energy relationships) Students should understand simple harmonic motion, so they can:		
a) Sketch or identify a graph of displacement as a function of time, and determine from such a graph the amplitude, period, and frequency of the motion.	✓	✓

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b) Write down an appropriate expression for displacement of the form $A \sin \omega t$ or $A \cos \omega t$ to describe the motion.	✓	✓
c) Find an expression for velocity as a function of time.		✓
d) State the relations between acceleration, velocity, and displacement, and identify points in the motion where these quantities are zero or achieve their greatest positive and negative values.	✓	✓
e) State and apply the relation between frequency and period.	✓	✓
f) Recognize that a system that obeys a differential equation of the form $d^2x/dt^2 = -\omega^2 x$ must execute simple harmonic motion, and determine the frequency and period of such motion.		✓
g) State how the total energy of an oscillating system depends on the amplitude of the motion, sketch or identify a graph of kinetic or potential energy as a function of time, and identify points in the motion where this energy is all potential or all kinetic.	✓	✓
h) Calculate the kinetic and potential energies of an oscillating system as functions of time, sketch or identify graphs of these functions, and prove that the sum of kinetic and potential energy is constant.	✓	✓
i) Calculate the maximum displacement or velocity of a particle that moves in simple harmonic motion with specified initial position and velocity.		✓
j) Develop a qualitative understanding of resonance so they can identify situations in which a system will resonate in response to a sinusoidal external force.		✓
2. Mass on a spring Students should be able to apply their knowledge of simple harmonic motion to the case of a mass on a spring, so they can:		
a) Derive the expression for the period of oscillation of a mass on a spring.		✓
b) Apply the expression for the period of oscillation of a mass on a spring.	✓	✓
c) Analyze problems in which a mass hangs from a spring and oscillates vertically.	✓	✓
d) Analyze problems in which a mass attached to a spring oscillates horizontally.	✓	✓
e) Determine the period of oscillation for systems involving series or parallel combinations of identical springs, or springs of differing lengths.		✓
3. Pendulum and other oscillations Students should be able to apply their knowledge of simple harmonic motion to the case of a pendulum, so they can:		
a) Derive the expression for the period of a simple pendulum.		✓
b) Apply the expression for the period of a simple pendulum.	✓	✓
c) State what approximation must be made in deriving the period.	✓	✓
d) Analyze the motion of a torsional pendulum or physical pendulum in order to determine the period of small oscillations.		✓
4. Newton's law of gravity Students should know Newton's Law of Universal Gravitation, so they can:		
a) Determine the force that one spherically symmetrical mass exerts on another.	✓	✓
b) Determine the strength of the gravitational field at a specified point outside a spherically symmetrical mass.	✓	✓
c) Describe the gravitational force inside and outside a uniform sphere, and calculate how the field at the surface depends on the radius and density of the sphere.		✓

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5. Orbits of planets and satellites Students should understand the motion of an object in orbit under the influence of gravitational forces, so they can:		
a) For a circular orbit:		
(1) Recognize that the motion does not depend on the object's mass; describe qualitatively how the velocity, period of revolution, and centripetal acceleration depend upon the radius of the orbit; and derive expressions for the velocity and period of revolution in such an orbit.	✓	✓
(2) Derive Kepler's Third Law for the case of circular orbits.	✓	✓
(3) Derive and apply the relations among kinetic energy, potential energy, and total energy for such an orbit.		✓
b) For a general orbit:		
(1) State Kepler's three laws of planetary motion and use them to describe in qualitative terms the motion of an object in an elliptical orbit.		✓
(2) Apply conservation of angular momentum to determine the velocity and radial distance at any point in the orbit.		✓
(3) Apply angular momentum conservation and energy conservation to relate the speeds of an object at the two extremes of an elliptical orbit.		✓
(4) Apply energy conservation in analyzing the motion of an object that is projected straight up from a planet's surface or that is projected directly toward the planet from far above the surface.		✓
II. FLUID MECHANICS AND THERMAL PHYSICS		
A. Fluid Mechanics		
1. Hydrostatic pressure Students should understand the concept of pressure as it applies to fluids, so they can:		
a) Apply the relationship between pressure, force, and area.	✓	
b) Apply the principle that a fluid exerts pressure in all directions.	✓	
c) Apply the principle that a fluid at rest exerts pressure perpendicular to any surface that it contacts.	✓	
d) Determine locations of equal pressure in a fluid.	✓	
e) Determine the values of absolute and gauge pressure for a particular situation.	✓	
f) Apply the relationship between pressure and depth in a liquid, $\Delta P = \rho g \, \Delta h$.	✓	
2. Buoyancy Students should understand the concept of buoyancy, so they can:		
a) Determine the forces on an object immersed partly or completely in a liquid.	✓	
b) Apply Archimedes' principle to determine buoyant forces and densities of solids and liquids.	✓	
3. Fluid flow continuity Students should understand the equation of continuity so that they can apply it to fluids in motion.	✓	
4. Bernoulli's equation Students should understand Bernoulli's equation so that they can apply it to fluids in motion.	✓	

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B. Temperature and heat		
1. Mechanical equivalent of heat Students should understand the "mechanical equivalent of heat" so they can determine how much heat can be produced by the performance of a specified quantity of mechanical work.	✓	
2. Heat transfer and thermal expansion Students should understand heat transfer and thermal expansion, so they can:		
a) Calculate how the flow of heat through a slab of material is affected by changes in the thickness or area of the slab, or the temperature difference between the two faces of the slab.	✓	
b) Analyze what happens to the size and shape of an object when it is heated.	✓	
c) Analyze qualitatively the effects of conduction, radiation, and convection in thermal processes.	✓	
C. Kinetic theory and thermodynamics		
1. Ideal gases		
a) Students should understand the kinetic theory model of an ideal gas, so they can:		
(1) State the assumptions of the model.	✓	
(2) State the connection between temperature and mean translational kinetic energy, and apply it to determine the mean speed of gas molecules as a function of their mass and the temperature of the gas.	✓	
(3) State the relationship among Avogadro's number, Boltzmann's constant, and the gas constant R, and express the energy of a mole of a monatomic ideal gas as a function of its temperature.	✓	
(4) Explain qualitatively how the model explains the pressure of a gas in terms of collisions with the container walls, and explain how the model predicts that, for fixed volume, pressure must be proportional to temperature.	✓	
b) Students should know how to apply the ideal gas law and thermodynamic principles, so they can:		
(1) Relate the pressure and volume of a gas during an isothermal expansion or compression.	✓	
(2) Relate the pressure and temperature of a gas during constant-volume heating or cooling, or the volume and temperature during constant-pressure heating or cooling.	✓	
(3) Calculate the work performed on or by a gas during an expansion or compression at constant pressure.	✓	
(4) Understand the process of adiabatic expansion or compression of a gas.	✓	
(5) Identify or sketch on a *PV* diagram the curves that represent each of the above processes.	✓	
2. Laws of thermodynamics		
a) Students should know how to apply the first law of thermodynamics, so they can:		
(1) Relate the heat absorbed by a gas, the work performed by the gas, and the internal energy change of the gas for any of the processes above.	✓	
(2) Relate the work performed by a gas in a cyclic process to the area enclosed by a curve on a *PV* diagram.	✓	
b) Students should understand the second law of thermodynamics, the concept of entropy, and heat engines and the Carnot cycle, so they can:		
(1) Determine whether entropy will increase, decrease, or remain the same during a particular situation.	✓	

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(2) Compute the maximum possible efficiency of a heat engine operating between two given temperatures.	✓	
(3) Compute the actual efficiency of a heat engine.	✓	
(4) Relate the heats exchanged at each thermal reservoir in a Carnot cycle to the temperatures of the reservoirs.	✓	
III. ELECTRICITY AND MAGNETISM		
A. Electrostatics		
1. Charge and Coulomb's Law		
a) Students should understand the concept of electric charge, so they can:		
(1) Describe the types of charge and the attraction and repulsion of charges.	✓	✓
(2) Describe polarization and induced charges.	✓	✓
b) Students should understand Coulomb's Law and the principle of superposition, so they can:		
(1) Calculate the magnitude and direction of the force on a positive or negative charge due to other specified point charges.	✓	✓
(2) Analyze the motion of a particle of specified charge and mass under the influence of an electrostatic force.	✓	✓
2. Electric field and electric potential (including point charges)		
a) Students should understand the concept of electric field, so they can:		
(1) Define it in terms of the force on a test charge.	✓	✓
(2) Describe and calculate the electric field of a single point charge.	✓	✓
(3) Calculate the magnitude and direction of the electric field produced by two or more point charges.	✓	✓
(4) Calculate the magnitude and direction of the force on a positive or negative charge placed in a specified field.	✓	✓
(5) Interpret an electric field diagram.	✓	✓
(6) Analyze the motion of a particle of specified charge and mass in a uniform electric field.	✓	✓
b) Students should understand the concept of electric potential, so they can:		
(1) Determine the electric potential in the vicinity of one or more point charges.	✓	✓
(2) Calculate the electrical work done on a charge or use conservation of energy to determine the speed of a charge that moves through a specified potential difference.	✓	✓
(3) Determine the direction and approximate magnitude of the electric field at various positions given a sketch of equipotentials.	✓	✓
(4) Calculate the potential difference between two points in a uniform electric field, and state which point is at the higher potential.	✓	✓
(5) Calculate how much work is required to move a test charge from one location to another in the field of fixed point charges.	✓	✓
(6) Calculate the electrostatic potential energy of a system of two or more point charges, and calculate how much work is required to establish the charge system.	✓	✓
(7) Use integration to determine electric potential difference between two points on a line, given electric field strength as a function of position along that line.		✓
(8) State the general relationship between field and potential, and define and apply the concept of a conservative electric field.		✓

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3. Gauss's law		
a) Students should understand the relationship between electric field and electric flux, so they can:		
(1) Calculate the flux of an electric field through an arbitrary surface or of a field uniform in magnitude over a Gaussian surface and perpendicular to it.		✓
(2) Calculate the flux of the electric field through a rectangle when the field is perpendicular to the rectangle and a function of one coordinate only.		✓
(3) State and apply the relationship between flux and lines of force.		✓
b) Students should understand Gauss's Law, so they can:		
(1) State the law in integral form, and apply it qualitatively to relate flux and electric charge for a specified surface.		✓
(2) Apply the law, along with symmetry arguments, to determine the electric field for a planar, spherical, or cylindrically symmetric charge distribution.		✓
(3) Apply the law to determine the charge density or total charge on a surface in terms of the electric field near the surface.		✓
4. Fields and potentials of other charge distributions		
a) Students should be able to use the principle of superposition to calculate by integration:		
(1) The electric field of a straight, uniformly charged wire.		✓
(2) The electric field and potential on the axis of a thin ring of charge, or at the center of a circular arc of charge.		✓
(3) The electric potential on the axis of a uniformly charged disk.		✓
b) Students should know the fields of highly symmetric charge distributions, so they can:		
(1) Identify situations in which the direction of the electric field produced by a charge distribution can be deduced from symmetry considerations.		✓
(2) Describe qualitatively the patterns and variation with distance of the electric field of:		
(a) Oppositely-charged parallel plates.		✓
(b) A long, uniformly-charged wire, or thin cylindrical or spherical shell.		✓
(3) Use superposition to determine the fields of parallel charged planes, coaxial cylinders, or concentric spheres.		✓
(4) Derive expressions for electric potential as a function of position in the above cases.		✓
B. Conductors, capacitors, dielectrics		
1. Electrostatics with conductors		
a) Students should understand the nature of electric fields in and around conductors, so they can:		
(1) Explain the mechanics responsible for the absence of electric field inside a conductor, and know that all excess charge must reside on the surface of the conductor.	✓	✓
(2) Explain why a conductor must be an equipotential, and apply this principle in analyzing what happens when conductors are connected by wires.	✓	✓
(3) Show that all excess charge on a conductor must reside on its surface and that the field outside the conductor must be perpendicular to the surface.		✓
b) Students should be able to describe and sketch a graph of the electric field and potential inside and outside a charged conducting sphere.	✓	✓

Objectives for the AP® Physics Courses	AP Course	
	B	C
c) Students should understand induced charge and electrostatic shielding, so they can:		
(1) Describe the process of charging by induction.	✓	✓
(2) Explain why a neutral conductor is attracted to a charged object.	✓	✓
(3) Explain why there can be no electric field in a charge-free region completely surrounded by a single conductor, and recognize consequences of this result.		✓
(4) Explain why the electric field outside a closed conducting surface cannot depend on the precise location of charge in the space enclosed by the conductor, and identify consequences of this result.		✓
2. Capacitors		
a) Students should understand the definition and function of capacitance, so they can:		
(1) Relate stored charge and voltage for a capacitor.	✓	✓
(2) Relate voltage, charge, and stored energy for a capacitor.	✓	✓
(3) Recognize situations in which energy stored in a capacitor is converted to other forms.	✓	✓
b) Students should understand the physics of the parallel-plate capacitor, so they can:		
(1) Describe the electric field inside the capacitor, and relate the strength of this field to the potential difference between the plates and the plate separation.	✓	✓
(2) Relate the electric field to the density of the charge on the plates.		✓
(3) Derive an expression for the capacitance of a parallel-plate capacitor.		✓
(4) Determine how changes in dimension will affect the value of the capacitance.	✓	✓
(5) Derive and apply expressions for the energy stored in a parallel-plate capacitor and for the energy density in the field between the plates.		✓
(6) Analyze situations in which capacitor plates are moved apart or moved closer together, or in which a conducting slab is inserted between capacitor plates, either with a battery connected between the plates or with the charge on the plates held fixed.		✓
c) Students should understand cylindrical and spherical capacitors, so they can:		
(1) Describe the electric field inside each.		✓
(2) Derive an expression for the capacitance of each.		✓
3. Dielectrics Students should understand the behavior of dielectrics, so they can:		
a) Describe how the insertion of a dielectric between the plates of a charged parallel-plate capacitor affects its capacitance and the field strength and voltage between the plates.		✓
b) Analyze situations in which a dielectric slab is inserted between the plates of a capacitor.		✓
C. Electric circuits		
1. Current, resistance, power		
a) Students should understand the definition of electric current, so they can relate the magnitude and direction of the current to the rate of flow of positive and negative charge.	✓	✓
b) Students should understand conductivity, resistivity, and resistance, so they can:		
(1) Relate current and voltage for a resistor.	✓	✓
(2) Write the relationship between electric field strength and current density in a conductor, and describe, in terms of the drift velocity of electrons, why such a relationship is plausible.		✓

Objectives for the AP® Physics Courses	AP Course	
	B	**C**
(3) Describe how the resistance of a resistor depends upon its length and cross-sectional area, and apply this result in comparing current flow in resistors of different material or different geometry.	✓	✓
(4) Derive an expression for the resistance of a resistor of uniform cross-section in terms of its dimensions and the resistivity of the material from which it is constructed.		✓
(5) Derive expressions that relate the current, voltage, and resistance to the rate at which heat is produced when current passes through a resistor.		✓
(6) Apply the relationships for the rate of heat production in a resistor.	✓	✓
2. Steady-state direct current circuits with batteries and resistors only		
a) Students should understand the behavior of series and parallel combinations of resistors, so they can:		
(1) Identify on a circuit diagram whether resistors are in series or in parallel.	✓	✓
(2) Determine the ratio of the voltages across resistors connected in series or the ratio of the currents through resistors connected in parallel.	✓	✓
(3) Calculate the equivalent resistance of a network of resistors that can be broken down into series and parallel combinations.	✓	✓
(4) Calculate the voltage, current, and power dissipation for any resistor in such a network of resistors connected to a single power supply.	✓	✓
(5) Design a simple series-parallel circuit that produces a given current through and potential difference across one specified component, and draw a diagram for the circuit using conventional symbols.	✓	✓
b) Students should understand the properties of ideal and real batteries, so they can:		
(1) Calculate the terminal voltage of a battery of specified emf and internal resistance from which a known current is flowing.	✓	✓
(2) Calculate the rate at which a battery is supplying energy to a circuit or is being charged up by a circuit.		✓
c) Students should be able to apply Ohm’s law and Kirchhoff’s rules to direct-current circuits, in order to:		
(1) Determine a single unknown current, voltage, or resistance.	✓	✓
(2) Set up and solve simultaneous equations to determine two unknown currents.		✓
d) Students should understand the properties of voltmeters and ammeters, so they can:		
(1) State whether the resistance of each is high or low.	✓	✓
(2) Identify or show correct methods of connecting meters into circuits in order to measure voltage or current.	✓	✓
(3) Assess qualitatively the effect of finite meter resistance on a circuit into which these meters are connected.		✓
3. Capacitors in circuits		
a) Students should understand the $t = 0$ and steady-state behavior of capacitors connected in series or in parallel, so they can:		
(1) Calculate the equivalent capacitance of a series or parallel combination.	✓	✓
(2) Describe how stored charge is divided between capacitors connected in parallel.	✓	✓
(3) Determine the ratio of voltages for capacitors connected in series.	✓	✓
(4) Calculate the voltage or stored charge, under steady-state conditions, for a capacitor connected to a circuit consisting of a battery and resistors.	✓	✓

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	B	C
b) Students should understand the discharging or charging of a capacitor through a resistor, so they can:		
(1) Calculate and interpret the time constant of the circuit.		✓
(2) Sketch or identify graphs of stored charge or voltage for the capacitor, or of current or voltage for the resistor, and indicate on the graph the significance of the time constant.		✓
(3) Write expressions to describe the time dependence of the stored charge or voltage for the capacitor, or of the current or voltage for the resistor.		✓
(4) Analyze the behavior of circuits containing several capacitors and resistors, including analyzing or sketching graphs that correctly indicate how voltages and currents vary with time.		✓
D. Magnetic Fields		
1. Forces on moving charges in magnetic fields		
Students should understand the force experienced by a charged particle in a magnetic field, so they can:		
a) Calculate the magnitude and direction of the force in terms of q, **v**, and, **B**, and explain why the magnetic force can perform no work.	✓	✓
b) Deduce the direction of a magnetic field from information about the forces experienced by charged particles moving through that field.	✓	✓
c) Describe the paths of charged particles moving in uniform magnetic fields.	✓	✓
d) Derive and apply the formula for the radius of the circular path of a charge that moves perpendicular to a uniform magnetic field.	✓	✓
e) Describe under what conditions particles will move with constant velocity through crossed electric and magnetic fields.	✓	✓
2. Forces on current-carrying wires in magnetic fields		
Students should understand the force exerted on a current-carrying wire in a magnetic field, so they can:		
a) Calculate the magnitude and direction of the force on a straight segment of current-carrying wire in a uniform magnetic field.	✓	✓
b) Indicate the direction of magnetic forces on a current-carrying loop of wire in a magnetic field, and determine how the loop will tend to rotate as a consequence of these forces.	✓	✓
c) Calculate the magnitude and direction of the torque experienced by a rectangular loop of wire carrying a current in a magnetic field.		✓
3. Fields of long current-carrying wires		
Students should understand the magnetic field produced by a long straight current-carrying wire, so they can:		
a) Calculate the magnitude and direction of the field at a point in the vicinity of such a wire.	✓	✓
b) Use superposition to determine the magnetic field produced by two long wires.	✓	✓
c) Calculate the force of attraction or repulsion between two long current-carrying wires.	✓	✓
4. Biot-Savart law and Ampere's law		
a) Students should understand the Biot-Savart Law, so they can:		
(1) Deduce the magnitude and direction of the contribution to the magnetic field made by a short straight segment of current-carrying wire.		✓
(2) Derive and apply the expression for the magnitude of **B** on the axis of a circular loop of current.		✓

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	B	C
b) Students should understand the statement and application of Ampere's Law in integral form, so they can:		
(1) State the law precisely.		✓
(2) Use Ampere's law, plus symmetry arguments and the right-hand rule, to relate magnetic field strength to current for planar or cylindrical symmetries.		✓
c) Students should be able to apply the superposition principle so they can determine the magnetic field produced by combinations of the configurations listed above.		✓
E. Electromagnetism		
1. Electromagnetic induction (including Faraday's law and Lenz's law)		
a) Students should understand the concept of magnetic flux, so they can:		
(1) Calculate the flux of a uniform magnetic field through a loop of arbitrary orientation.	✓	✓
(2) Use integration to calculate the flux of a non-uniform magnetic field, whose magnitude is a function of one coordinate, through a rectangular loop perpendicular to the field.		✓
b) Students should understand Faraday's law and Lenz's law, so they can:		
(1) Recognize situations in which changing flux through a loop will cause an induced emf or current in the loop.	✓	✓
(2) Calculate the magnitude and direction of the induced emf and current in a loop of wire or a conducting bar under the following conditions:		
(a) The magnitude of a related quantity such as magnetic field or area of the loop is changing at a constant rate.	✓	✓
(b) The magnitude of a related quantity such as magnetic field or area of the loop is a specified non-linear function of time.		✓
c) Students should be able to analyze the forces that act on induced currents so they can determine the mechanical consequences of those forces.		✓
2. Inductance (including *LR* and *LC* circuits)		
a) Students should understand the concept of inductance, so they can:		
(1) Calculate the magnitude and sense of the emf in an inductor through which a specified changing current is flowing.		✓
(2) Derive and apply the expression for the self-inductance of a long solenoid.		✓
b) Students should understand the transient and steady state behavior of DC circuits containing resistors and inductors, so they can:		
(1) Apply Kirchhoff's rules to a simple *LR* series circuit to obtain a differential equation for the current as a function of time.		✓
(2) Solve the differential equation obtained in (1) for the current as a function of time through the battery, using separation of variables.		✓
(3) Calculate the initial transient currents and final steady state currents through any part of a simple series and parallel circuit containing an inductor and one or more resistors.		✓
(4) Sketch graphs of the current through or voltage across the resistors or inductor in a simple series and parallel circuit.		✓
(5) Calculate the rate of change of current in the inductor as a function of time.		✓
(6) Calculate the energy stored in an inductor that has a steady current flowing through it.		✓
3. Maxwell's equations Students should be familiar with Maxwell's equations so they can associate each equation with its implications.		✓

Objectives for the AP® Physics Courses	AP Course	
	B	C
IV. WAVES AND OPTICS		
A. Wave motion (including sound)		
1. Traveling waves Students should understand the description of traveling waves, so they can:		
a) Sketch or identify graphs that represent traveling waves and determine the amplitude, wavelength, and frequency of a wave from such a graph.	✓	
b) Apply the relation among wavelength, frequency, and velocity for a wave.	✓	
c) Understand qualitatively the Doppler effect for sound in order to explain why there is a frequency shift in both the moving-source and moving-observer case.	✓	
d) Describe reflection of a wave from the fixed or free end of a string.	✓	
e) Describe qualitatively what factors determine the speed of waves on a string and the speed of sound.	✓	
2. Wave propagation		
a) Students should understand the difference between transverse and longitudinal waves, and be able to explain qualitatively why transverse waves can exhibit polarization.	✓	
b) Students should understand the inverse-square law, so they can calculate the intensity of waves at a given distance from a source of specified power and compare the intensities at different distances from the source.	✓	
3. Standing waves Students should understand the physics of standing waves, so they can:		
a) Sketch possible standing wave modes for a stretched string that is fixed at both ends, and determine the amplitude, wavelength, and frequency of such standing waves.	✓	
b) Describe possible standing sound waves in a pipe that has either open or closed ends, and determine the wavelength and frequency of such standing waves.	✓	
4. Superposition Students should understand the principle of superposition, so they can apply it to traveling waves moving in opposite directions, and describe how a standing wave may be formed by superposition.	✓	
B. Physical optics		
1. Interference and diffraction Students should understand the interference and diffraction of waves, so they can:		
a) Apply the principles of interference to coherent sources in order to:		
(1) Describe the conditions under which the waves reaching an observation point from two or more sources will all interfere constructively, or under which the waves from two sources will interfere destructively.	✓	
(2) Determine locations of interference maxima or minima for two sources or determine the frequencies or wavelengths that can lead to constructive or destructive interference at a certain point.	✓	
(3) Relate the amplitude produced by two or more sources that interfere constructively to the amplitude and intensity produced by a single source.	✓	
b) Apply the principles of interference and diffraction to waves that pass through a single or double slit or through a diffraction grating, so they can:		
(1) Sketch or identify the intensity pattern that results when monochromatic waves pass through a single slit and fall on a distant screen, and describe how this pattern will change if the slit width or the wavelength of the waves is changed.	✓	

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(2) Calculate, for a single-slit pattern, the angles or the positions on a distant screen where the intensity is zero.	✓	
(3) Sketch or identify the intensity pattern that results when monochromatic waves pass through a double slit, and identify which features of the pattern result from single-slit diffraction and which from two-slit interference.	✓	
(4) Calculate, for a two-slit interference pattern, the angles or the positions on a distant screen at which intensity maxima or minima occur.	✓	
(5) Describe or identify the interference pattern formed by a diffraction grating, calculate the location of intensity maxima, and explain qualitatively why a multiple-slit grating is better than a two-slit grating for making accurate determinations of wavelength.	✓	
c) Apply the principles of interference to light reflected by thin films, so they can:		
(1) State under what conditions a phase reversal occurs when light is reflected from the interface between two media of different indices of refraction.	✓	
(2) Determine whether rays of monochromatic light reflected perpendicularly from two such interfaces will interfere constructively or destructively, and thereby account for Newton's rings and similar phenomena, and explain how glass may be coated to minimize reflection of visible light.	✓	
2. Dispersion of light and the electromagnetic spectrum Students should understand dispersion and the electromagnetic spectrum, so they can:		
a) Relate a variation of index of refraction with frequency to a variation in refraction.	✓	
b) Know the names associated with electromagnetic radiation and be able to arrange in order of increasing wavelength the following: visible light of various colors, ultraviolet light, infrared light, radio waves, x-rays, and gamma rays.	✓	
C. Geometric optics		
1. Reflection and refraction Students should understand the principles of reflection and refraction, so they can:		
a) Determine how the speed and wavelength of light change when light passes from one medium into another.	✓	
b) Show on a diagram the directions of reflected and refracted rays.	✓	
c) Use Snell's Law to relate the directions of the incident ray and the refracted ray, and the indices of refraction of the media.	✓	
d) Identify conditions under which total internal reflection will occur.	✓	
2. Mirrors Students should understand image formation by plane or spherical mirrors, so they can:		
a) Locate by ray tracing the image of an object formed by a plane mirror, and determine whether the image is real or virtual, upright or inverted, enlarged or reduced in size.	✓	
b) Relate the focal point of a spherical mirror to its center of curvature.	✓	
c) Locate by ray tracing the image of a real object, given a diagram of a mirror with the focal point shown, and determine whether the image is real or virtual, upright or inverted, enlarged or reduced in size.	✓	
d) Use the mirror equation to relate the object distance, image distance, and focal length for a lens, and determine the image size in terms of the object size.	✓	

Objectives for the AP® Physics Courses	AP Course	
	B	C
3. Lenses Students should understand image formation by converging or diverging lenses, so they can:		
a) Determine whether the focal length of a lens is increased or decreased as a result of a change in the curvature of its surfaces, or in the index of refraction of the material of which the lens is made, or the medium in which it is immersed.	✓	
b) Determine by ray tracing the location of the image of a real object located inside or outside the focal point of the lens, and state whether the resulting image is upright or inverted, real or virtual.	✓	
c) Use the thin lens equation to relate the object distance, image distance, and focal length for a lens, and determine the image size in terms of the object size.	✓	
d) Analyze simple situations in which the image formed by one lens serves as the object for another lens.	✓	
V. ATOMIC AND NUCLEAR PHYSICS		
A. Atomic physics and quantum effects		
1. Photons, the photoelectric effect, Compton scattering, x-rays a) Students should know the properties of photons, so they can:		
(1) Relate the energy of a photon in joules or electron-volts to its wavelength or frequency.	✓	
(2) Relate the linear momentum of a photon to its energy or wavelength, and apply linear momentum conservation to simple processes involving the emission, absorption, or reflection of photons.	✓	
(3) Calculate the number of photons per second emitted by a monochromatic source of specific wavelength and power.	✓	
b) Students should understand the photoelectric effect, so they can:		
(1) Describe a typical photoelectric-effect experiment, and explain what experimental observations provide evidence for the photon nature of light.	✓	
(2) Describe qualitatively how the number of photoelectrons and their maximum kinetic energy depend on the wavelength and intensity of the light striking the surface, and account for this dependence in terms of a photon model of light.	✓	
(3) Determine the maximum kinetic energy of photoelectrons ejected by photons of one energy or wavelength, when given the maximum kinetic energy of photoelectrons for a different photon energy or wavelength.	✓	
(4) Sketch or identify a graph of stopping potential versus frequency for a photoelectric-effect experiment, determine from such a graph the threshold frequency and work function, and calculate an approximate value of h/e.	✓	
c) Students should understand Compton scattering, so they can:		
(1) Describe Compton's experiment, and state what results were observed and by what sort of analysis these results may be explained.	✓	
(2) Account qualitatively for the increase of photon wavelength that is observed, and explain the significance of the Compton wavelength.	✓	
d) Students should understand the nature and production of x-rays, so they can calculate the shortest wavelength of x-rays that may be produced by electrons accelerated through a specified voltage.	✓	

Objectives for the AP® Physics Courses	AP Course	
	B	**C**
2. Atomic energy levels Students should understand the concept of energy levels for atoms, so they can:		
a) Calculate the energy or wavelength of the photon emitted or absorbed in a transition between specified levels, or the energy or wavelength required to ionize an atom.	✓	
b) Explain qualitatively the origin of emission or absorption spectra of gases.	✓	
c) Calculate the wavelength or energy for a single-step transition between levels, given the wavelengths or energies of photons emitted or absorbed in a two-step transition between the same levels.	✓	
d) Draw a diagram to depict the energy levels of an atom when given an expression for these levels, and explain how this diagram accounts for the various lines in the atomic spectrum.	✓	
3. Wave-particle duality Students should understand the concept of de Broglie wavelength, so they can:		
a) Calculate the wavelength of a particle as a function of its momentum.	✓	
b) Describe the Davisson-Germer experiment, and explain how it provides evidence for the wave nature of electrons.	✓	
B. Nuclear Physics		
1. Nuclear reactions (including conservation of mass number and charge)		
a) Students should understand the significance of the mass number and charge of nuclei, so they can:		
(1) Interpret symbols for nuclei that indicate these quantities.	✓	
(2) Use conservation of mass number and charge to complete nuclear reactions.	✓	
(3) Determine the mass number and charge of a nucleus after it has undergone specified decay processes.	✓	
b) Students should know the nature of the nuclear force, so they can compare its strength and range with those of the electromagnetic force.	✓	
c) Students should understand nuclear fission, so they can describe a typical neutron-induced fission and explain why a chain reaction is possible.	✓	
2. Mass-energy equivalence Students should understand the relationship between mass and energy (mass-energy equivalence), so they can:		
a) Qualitatively relate the energy released in nuclear processes to the change in mass.	✓	
b) Apply the relationship $\Delta E = (\Delta m)c^2$ in analyzing nuclear processes.	✓	
LABORATORY AND EXPERIMENTAL SITUATIONS These objectives overlay the content objectives, and are assessed in the context of those objectives.		
1. Design experiments Students should understand the process of designing experiments, so they can:		
a) Describe the purpose of an experiment or a problem to be investigated.	✓	✓
b) Identify equipment needed and describe how it is to be used.	✓	✓
c) Draw a diagram or provide a description of an experimental setup.	✓	✓
d) Describe procedures to be used, including controls and measurements to be taken.	✓	✓
2. Observe and measure real phenomena Students should be able to make relevant observations, and be able to take measurements with a variety of instruments (cannot be assessed via paper-and-pencil examinations).		

Objectives for the AP® Physics Courses	**AP Course**	
	B	**C**
3. Analyze data Students should understand how to analyze data, so they can:		
a) Display data in graphical or tabular form.	✓	✓
b) Fit lines and curves to data points in graphs.	✓	✓
c) Perform calculations with data.	✓	✓
d) Make extrapolations and interpolations from data.	✓	✓
4. Analyze errors Students should understand measurement and experimental error, so they can:		
a) Identify sources of error and how they propagate.	✓	✓
b) Estimate magnitude and direction of errors.	✓	✓
c) Determine significant digits.	✓	✓
d) Identify ways to reduce error.	✓	✓
5. Communicate results Students should understand how to summarize and communicate results, so they can:		
a) Draw inferences and conclusions from experimental data.	✓	✓
b) Suggest ways to improve experiment.	✓	✓
c) Propose questions for further study.	✓	✓